## LCA Case Studies

# Life Cycle Assessment of the District Heat Distribution System

## Part 2: Network Construction

**Part 1: Pipe Production [Int J LCA 9 (2) 130–136 (2004)] • Part 2: Network Construction [Int J LCA 10 (6) 425–435 (2005)]**
**Part 3: Use Phase and Overall Discussion [DOI: http://dx.doi.org/10.1065/lca2005.08.225]**

**Preamble.** This series of three papers is based on research performed for the Swedish District Heating Association with the purpose of mapping the environmental life cycle impacts from the different phases involved in district heat distribution. **Part 1** concerns production of district heating pipes while **Part 2** describes construction of the district heating pipe network. In Part 3, the use phase is evaluated based on heat losses from the network during heat distribution. **Part 3** also includes a discussion in which the three evaluated life cycle phases are compared.

**Morgan Fröling and Magdalena Svanström***

Chemical Environmental Science, Chalmers University of Technology, 412 96 Göteborg, Sweden

* **Corresponding author** (magdalena.svanstrom@chemeng.chalmers.se)

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**Abstract**

**Goal, Scope and Background.** In a district heating network, hot water is transported from a central heat generation plant to buildings where the heat is utilised for space heating and domestic hot water generation. This paper presents a life cycle assessment of the construction of district heating pipe networks, based on a gate-to-gate life cycle inventory commissioned by the Swedish District Heating Association. In the literature, environmental studies on district heating mainly consider emissions from heat generation; environmental impacts from construction of the distribution system are seldom discussed. The purpose of the study is to identify environmentally significant parts in the construction of district heat distribution networks and to provide information for a larger study including more parts of the life cycle of such district heat distribution. No external review has been performed, but a reference group of district heating experts familiar with the practice was involved in the choice of systems to be studied as well as in reviewing parts of the study.

**Methods.** The study covers construction of the main pipe system according to the guidelines from the Swedish District Heating Association. Construction of the pipe system was assumed to take place in Sweden by Swedish entrepreneurs during the time period 1999–2000. Transport of the district heating pipes from the factory to the excavation site is included in this study, but not the production of the pipes. The functional unit used in the study is 100 metres of pipe system (flow and return pipe). The studied systems are: twin pipe of the dimension DN25 and single pipes of the dimensions DN25, DN100 and DN500. Two different surroundings were studied: urban environment, characterised by the need to break open and to restore asphalt cover and to remove excavated material from the site, and green areas, without any asphalt and where some of the excavated material might be left at the site and reused.

**Results and Discussion.** A short description of the inventory, some inventory results and life cycle impact assessments are presented. Characterisations according to GWP, AP, POCP and resource depletion are given as well as two weightings: Eco-Indicator99 and Ecoscarcity. Emissions from production and use of the diesel needed for excavation of the pipe trench gives rise to a dominating part of the environmental impact.

**Recommendations and Perspective.** To minimise the need for excavation is the most important feature in order to reduce the environmental impact from construction of the district heating pipe network. A twin pipe uses a narrower pipe trench than the equivalent two single pipes, and is an already available option. Co-utilising the trenches with cables for electricity, for instance, will not make the environmental impact from the trench any smaller, but will decrease the total need for excavation in society. It is important to make sure that environmental improvements from changes in the network construction phase are not off-set by other effects in the total life cycle of district heat distribution.

**Keywords:** District heat distribution; district heating pipe; excavation; laying; network construction

### Introduction

In a district heating network, hot water is transported from a central heat generation plant to buildings where the heat is utilised for space heating and domestic hot water generation. District heating is used in many countries in northern Europe, providing benefits like fewer chimneys and better air quality in dwelling areas. District heating can utilise waste heat and is therefore a potential heat sink for increased use of combined heat and power production. Like the infrastructure for many utilities, the district heating pipe system is often buried under streets and sidewalks. The necessary excavation and construction work generates environmental impacts. In the literature, environmental studies on district heating mainly consider the emissions from heat generation; the environmental impacts from construction of the distribution system are seldom discussed. In this study, the distribution system is considered. The life cycle of district heat distribution can be considered to consist of four phases: production of district heating pipes, construction of pipe networks, use of the networks and post-use handling of the networks. Environmental impacts from production of dis-

trict heating pipes have been studied earlier and the results were presented in Part 1 of this article series [1]. For energy companies constructing district heating pipe networks, as well as for people living beside construction sites and authorities trying to minimise the total environmental impact in a municipality, it is of interest to study and improve the construction of the network environmentally. In the present paper, the environmental impacts from construction of district heating pipe networks are considered. The purpose of the study is to identify environmentally significant parts in the construction of the networks and to provide information for a larger study including more parts of the life cycle of district heat distribution. The full inventory results have been published in Swedish and are available through the commissioner (the Swedish District Heating Association) [2]. A summary of the inventory results has been reported in English in a doctoral thesis by Fröling [3]. In this paper, an excerpt of the inventory results is presented together with an impact assessment.

## 1 System Description and Inventory

In this study, the construction of district heating pipe networks is considered. The district heating pipes consist of a steel tube, insulated with polyurethane foam to avoid large heat losses from the networks. A polyethylene (PE) casing protects the foam from damage, water intrusion and thermal ageing due to gas diffusion. The functional unit used in this study is construction of 100 metres of pipe system (including both flow and return pipe). The chosen functional unit does not directly reflect the function of the pipe network (i.e. heat distribution), but it was chosen to make it possible to use the results in larger system studies once more parts of the distribution system have been investigated with LCA methodology. The studied district heating pipes are: twin pipe of the dimension DN25 and single pipes of the dimensions DN25, DN100 and DN500. The characteristics of the studied district heating pipe dimensions are given in **Table 1**. In **Fig. 1**, crosscuts of pipe trenches are shown for single pipes and twin pipes, respectively, both with the dimension of DN25. For a twin pipe, only one district heating pipe is put in the excavated trench and, consequently, a broader pipe trench is needed when using single pipes. Two different surroundings were studied: *urban environment*, characterised by the need to break open and to restore asphalt cover and to remove excavated material from the site, and *green areas*, without any asphalt and where some of the excavated material might be left at the site and reused. This gives us, all in all, eight different scenarios – four different dimensions in two different surroundings. These eight scenarios represent realistic cases chosen with the purpose of highlighting different situations. Networks with pipes of different dimension are not directly interchangeable since they transport different amounts of hot water. The study is not intended to be a comparison between eight different options; any pipe network has to be designed based on the specific characteristics of the network, such as transportation length, heat load and network design limitations. The study covers construction of the main pipe system, but not the service pipes leading to separate buildings from the main pipe. So-called Series 2 insulation thickness is considered, which is commercially available and common in Northern Europe. No external review has been performed, but a reference group of district heating experts familiar with the practice was involved in the choice of systems to be studied as well as in reviewing parts of the study.

**Table 1:** Characteristics of the district heating pipe dimensions studied in the life cycle assessment of network construction. Each dimension is studied in two different surroundings: *green area* and *urban environment*

| Dimension – Pipe design | DN25 – Twin | DN25 – Single | DN100 – Single | DN500 – Single |
|---|---|---|---|---|
| Steel tube inner diameter (mm) | 31.4 | 31.4 | 110 | 502 |
| Steel tube thickness (mm) | 2.3 | 2.3 | 3.6 | 6.3 |
| PE casing, nominal outer diameter (mm) | 140 | 110 | 225 | 710 |
| PE casing thickness (mm) | 3.2 | 3.2 | 3.8 | 12 |
| Length of pipe unit (m) | 50 | 12 | 12 | 16 |

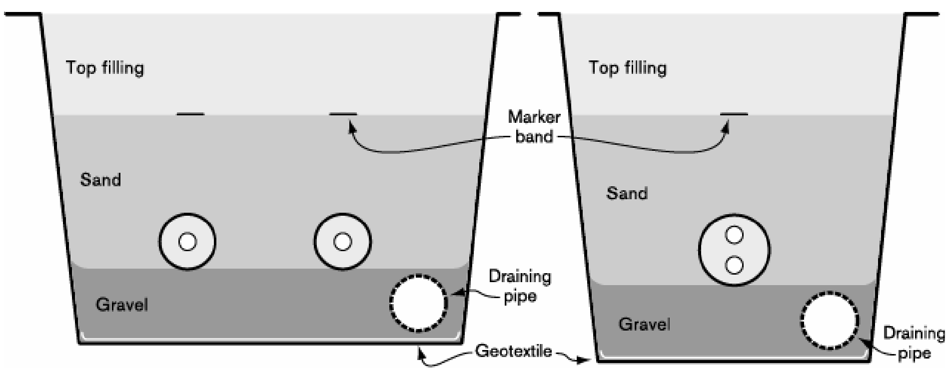


**Fig. 1:** Crosscut of a pipe trench according to the guidelines of the Swedish District Heating Association for DN25 single pipes and twin pipes, respectively [4]. DN25 is the smallest dimension of district heating pipes investigated in this study

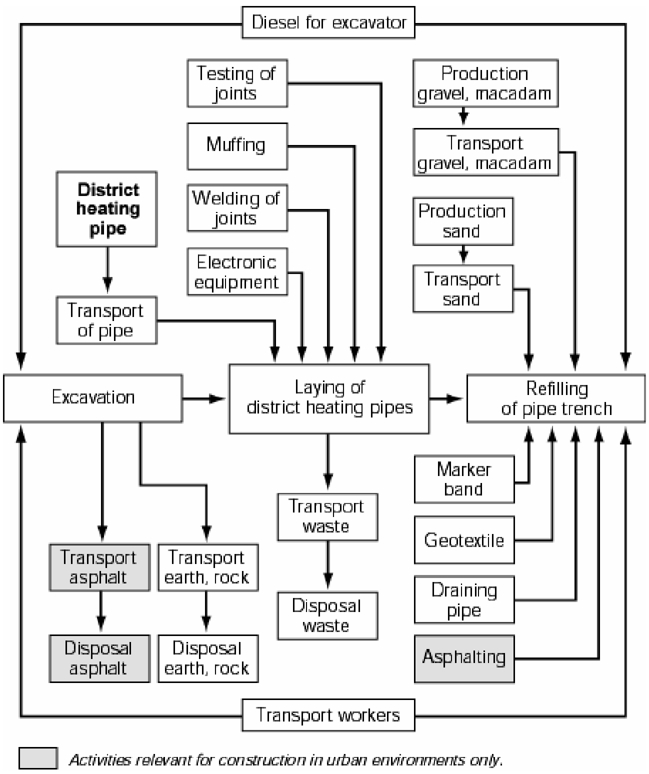


**Fig. 2:** LCA activities in the product system describing construction of district heating networks in an *urban environment*. Many boxes represent sub-level systems. The 'District heating pipe' box represents a non-elementary input to the system. Production of district heating pipes has been described elsewhere [1]

The activities that make up the investigated product system are shown in **Fig. 2**. Note that only top-level activities are shown. Many of the boxes in the figure represent an underlying system of activities. For *green areas*, activities involving removal and restoration of asphalt cover are not relevant.

Construction of district heating pipe networks according to the guidelines from the Swedish District Heating Association was studied [4] (see Fig. 1). Construction of the network was assumed to take place in Sweden by Swedish entrepreneurs during the time period 1999–2000. This study is based on typical conditions described by experienced entrepreneurs, and not on real cases. The results from this study depend on the specific conditions chosen in the study in terms of type and age of equipment, vehicles, etc.

For the top-level activities (shown in Fig. 2), most data has been gathered from entrepreneurs or other persons involved in the practical work. The data has been checked against information from other practitioners or literature data for similar activities. For other activities, generic data and average data from the literature have been used. The LCAiT (Life Cycle Inventory Tool) software [5] was used to handle the inventory information.

This study covers transport of the district heating pipes from the factory to the excavation site and construction of the district heating pipe network, but not production of the pipes, use of the pipes, or post-use handling. Construction of machines, vehicles and other equipment is not included. The working environment has not been evaluated. Local nuisances such as noise or aesthetic problems for people living, working, driving, etc. close to the excavation area have not been studied.

All environmental impacts are allocated to the district heating pipe system. District heating pipes leaving the factory represents a non-elementary input to the studied system. Non-elementary outputs are: waste disposed of at the top-level, copper scrap to recycling and the finished pipe network itself.

### 1.1 Excavation of pipe trench

Planning and design of the network was not included in the study. Excavation is normally easier to perform in *green areas*, e.g. because there are fewer other installations to avoid compared to in *urban environments*. In this study, it is assumed that no blasting is needed. In reality, the need for blasting differs very much and is difficult to predict. The volumes of excavated materials vary between the two different environments (**Table 2**). The slope of the trench walls is assumed to be 1:4 [4], which is a common wall slope when no blasting is performed (see Fig. 1). The excavation work was studied by interviewing practitioners. On the average, one man in an excavator and one man in the trench are needed during excavation of the pipe trenches. For excava-

**Table 2:** Volumes of excavated material sent to disposal, refilled materials and foam in pipe joint void. Volumes and areas are given per m of pipe trench or per void. Data was calculated from the guidelines of the Swedish District Heating Association [4]

| Dimension | Excavated material to disposal[1)] | | Foam | | Refilling material | | Asphalt[4)] | |
|---|---|---|---|---|---|---|---|---|
| | Urban Asphalt ($m^3$) | Urban Other ($m^3$) | Green ($m^3$) | Muffing void[2)] ($m^3$) | Gravel ($m^3$) | Sand ($m^3$) | Urban Macadam[3)] ($m^3$) | Area ($m^2$) |
| DN25, twin | 0.049 | 0.63 | 0.32 | 0.0069 | 0.077 | 0.22 | 0.30 | 0.87 |
| DN25, single | 0.062 | 0.83 | 0.43 | 0.0043 | 0.12 | 0.28 | 0.40 | 1.1 |
| DN100, single | 0.084 | 1.3 | 0.77 | 0.015 | 0.18 | 0.51 | 0.55 | 1.6 |
| DN500, single | 0.15 | 3.8 | 2.7 | 0.097 | 0.34 | 1.6 | 1.0 | 4.4 |

[1)] In green areas, some material is also left on site (about 20% of the total excavated volume; this is used for top filling)
[2)] Length 0.5 m
[3)] In green areas, excavated materials are used as top filling and the total pipe trench volume is smaller
[4)] Only urban areas

tion of a pipe trench for a DN100 single pipe system, a distance of 30–50 m can be excavated in *urban environments* during 8 h of work; in *green areas*: 70–100 m [2, 6]. For other dimensions, a linear relationship between distance excavated and trench volume has been assumed. Inventory data for diesel-fuelled [7] excavators [8] (Swedish conditions around 1990) were used. In practice, excavators with low emitting engines are often used in Swedish cities due to local regulations. This gives positive effects on the local air quality and the working environment, but will not strongly influence the results of the life cycle inventory due to an increase in fuel consumption for these engines. In the case of *urban environment*, asphalt has to be removed before excavation and all excavated materials have to be removed from the excavation site immediately. On the average, three trucks perform the shuttle service. Asphalt is sent to a separate landfill, which is estimated to be located 15 km away from the excavation site. The distance to the deposit for earth and rock is estimated to be 10 km. Medium trucks carrying a maximum load of 14 metric tons, driving in city traffic and with emissions according to the Euro2 requirements are assumed [9]. In *green areas*, excavated material does not immediately have to be removed. In fact, some of the material can often be used as refilling material (see 'Refilling of pipe trench' below).

### 1.2 Laying of district heating pipes

The district heating pipes are transported to the site (1000 km assumed) by medium truck [9] and put to place in the trenches. The expert group estimated the pipe spillage to 4% for DN100 and DN25, single, and 1% for DN500, single, and DN25, twin. The number of bends and T-connections differs between the pipe dimensions and was calculated from sales statistics from the Swedish district heating pipe manufacturer Powerpipe Systems AB [10]. The environmental impacts from these parts have been included as an increased number of joints. The steel joints are welded and eventually x-rayed to make sure that the quality is sufficient. Gas welding is assumed for all dimensions even though larger dimensions are normally electrically welded in Sweden. About 10% of the length of the welded steel joints is x-rayed, and insufficient quality is found in 2–3% of the joints. Alarm wires of copper for moisture detection run through all pipes. Before muffing, the copper wires are connected. Electronic surveillance equipment is assumed to be installed every 4000 metres of wire. The muff (polyethylene) is put into place, the polyethylene joint is electrically welded, and the empty space between the pipes, under the muff, is filled with polyurethane (PUR) foam (**Fig. 3**). The volume of foam needed to fill the empty void is shown in Table 2. Average European production data was used for polyol [11], isocyanate (MDI, methylene-diphenyl-4-4'-diisocyanate) [11] and polyethylene (HDPE) [12]. During welding and foaming, there are potential health effects from worker exposure to isocyanates. These effects were not evaluated in this study.

### 1.3 Refilling of pipe trench

Crosscuts of pipe trenches for single and twin pipes, respectively, are shown in Fig. 1. In *green areas*, about 20% of the excavated material is assumed to be put back into the pipe trenches as top filling. In the case of *urban environments*, all filling material has to be transported to the site and the surface is finally covered with new asphalt. The top filling layer is 20 cm thicker and the pipe trench is much deeper in *urban environments* to allow for traffic load. The volumes of different filling materials (see Table 2), were calculated from the recommendations for volumes of pipe trenches in the guidelines of the Swedish District Heating Association [4]. Inventory data for production of gravel and macadam is taken from the stone crusher of Sabema Material AB [13], and the sand is assumed to be pit run [14]. Transport distances of 15 km are assumed. The bottom of the pipe trench as well as the draining pipe (polypropylene) [12] is covered with a geo-textile (polypropylene) [12]. Draining pipes are assumed to be needed for half of the distance. Purple polyethylene marker bands [12] are put above the pipes to indicate the location of the district heating pipes in future excavations. Warm asphalting [14] was considered as the most common practice. An average asphalt thickness of 5 cm is estimated.

### 1.4 Transport of workers

When this study was performed, there was an on-going discussion in Sweden on whether the transports of workers to and from the construction sites of district heating networks contributed substantially to the total environmental impact from construction of district heating networks. Because of this, the transport of workers was included in this study and was studied as a separate activity. For workers performing muffing and welding, the transports are included in the 'Muffing' and 'Welding of joints' activities, respectively. The use of cars with catalytic converters was assumed [15]. In most cases, a distance of 50 km to the site was used.

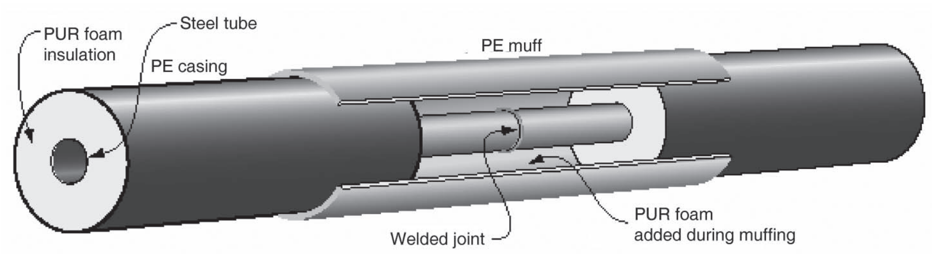


**Fig. 3:** District heating pipe joint [4]

## 2 Results and Discussion

The full inventory matrix has been published earlier [2]. In **Tables 3** and **4**, four inventory parameters are shown for the four studied dimensions for *urban environment* and *green areas*, respectively. Total characterisation and weighting results based on the full inventory list (not only the parameters shown in Tables 3 and 4), as well as sub-results for groups of activities, are presented in **Tables 5** and **6**, for *urban environment* and *green areas*, respectively. Activities have been aggregated where no important information is lost by doing so. Results are reported from characterisations according to global warming potential (GWP, 100 years [16]), acidification potential (AP [16]), photo oxidant creation potential (POCP, high $NO_x$-background [16]) and resource depletion (statistical reserve life [17]) as well as from two weighting methods: EcoIndicator99 [18] and Ecoscarcity [19].

**Table 3:** Inventory results for the four studied dimensions for district heating network construction in an *urban environment* [2]. Unit: kg/100 m pipe system. Inventory results regarding emissions of fossil carbon dioxide, nitrogen oxides and sulphur oxides to air and emissions of compounds contributing to oxygen demand in water (measured as chemical oxygen demand, COD) are shown. The total results for the system as well as sub-results for the activities shown in Fig. 1 are given

| **Network construction in *urban environment*** | **DN25, twin** | | | | **DN25, single** | | | |
|---|---|---|---|---|---|---|---|---|
| **Inventory parameter** | **$CO_2$** | **$NO_x$** | **$SO_2$** | **COD** | **$CO_2$** | **$NO_x$** | **$SO_2$** | **COD** |
| TRENCH | | | | | | | | |
| Excavator | 1100 | 20 | 0.97 | 0.050 | 1300 | 25 | 1.2 | 0.061 |
| Asphalt waste handling | 16 | 0.16 | 0.018 | 0.00072 | 21 | 0.20 | 0.022 | 0.00092 |
| Earth, rock waste handling | 190 | 1.8 | 0.20 | 0.0083 | 250 | 2.3 | 0.27 | 0.011 |
| Geotextile | 8.1 | 0.074 | 0.075 | 0.0027 | 12 | 0.11 | 0.11 | 0.0042 |
| Draining pipe | 79 | 0.49 | 0.48 | 0.012 | 79 | 0.49 | 0.48 | 0.012 |
| Marker band | 1.1 | 0.012 | 0.0070 | 0.00023 | 2.2 | 0.023 | 0.014 | 0.00046 |
| Production gravel, macadam | 25 | 0.18 | 0.025 | 0.00058 | 34 | 0.24 | 0.034 | 0.00078 |
| Transport gravel, macadam | 130 | 1.2 | 0.14 | 0.0057 | 170 | 1.7 | 0.19 | 0.0077 |
| Production sand | 6.9 | 0.059 | 0.0068 | 0.00013 | 8.7 | 0.075 | 0.0086 | 0.00016 |
| Transport sand | 85 | 0.80 | 0.092 | 0.0037 | 110 | 1.0 | 0.12 | 0.0047 |
| Asphalting | 240 | 0.66 | 0.43 | 0.15 | 290 | 0.81 | 0.53 | 0.18 |
| NETWORK | | | | | | | | |
| Transport pipe | 60 | 0.57 | 0.065 | 0.0027 | 120 | 1.2 | 0.14 | 0.0055 |
| Welding of joints | 4.0 | 0.0069 | 0.0037 | 0.000085 | 7.6 | 0.013 | 0.0070 | 0.00016 |
| Muffing | 33 | 0.20 | 0.12 | 0.0037 | 110 | 0.46 | 0.29 | 0.0068 |
| Testing of joints | 23 | 0.028 | 0.0082 | | 56 | 0.068 | 0.020 | |
| Electronic equipment | 2.4 | 0.0066 | 0.071 | 0.000018 | 4.9 | 0.013 | 0.14 | 0.000037 |
| Waste handling | 5.2 | 0.050 | 0.0056 | 0.00023 | 5.2 | 0.050 | 0.0056 | 0.00023 |
| TRANSPORT WORKERS | 22 | 0.026 | 0.0076 | | 27 | 0.032 | 0.0095 | |
| **TOTAL** | **2000** | **26** | **2.7** | **0.24** | **2600** | **34** | **3.6** | **0.30** |
| **Network construction in *urban environment*** | **DN100, single** | | | | **DN500, single** | | | |
| **Inventory parameter** | **$CO_2$** | **$NO_x$** | **$SO_2$** | **COD** | **$CO_2$** | **$NO_x$** | **$SO_2$** | **COD** |
| TRENCH | | | | | | | | |
| Excavator | 1500 | 28 | 1.3 | 0.068 | 2200 | 42 | 2.0 | 0.10 |
| Asphalt waste handling | 28 | 0.27 | 0.030 | 0.0012 | 51 | 0.48 | 0.055 | 0.0022 |
| Earth, rock waste handling | 400 | 3.8 | 0.43 | 0.017 | 1100 | 11 | 1.2 | 0.050 |
| Geotextile | 18 | 0.16 | 0.17 | 0.0061 | 35 | 0.32 | 0.32 | 0.012 |
| Draining pipe | 79 | 0.49 | 0.48 | 0.012 | 79 | 0.49 | 0.48 | 0.012 |
| Marker band | 2.2 | 0.023 | 0.014 | 0.00046 | 2.2 | 0.023 | 0.014 | 0.00046 |
| Production gravel, macadam | 48 | 0.34 | 0.048 | 0.0011 | 90 | 0.65 | 0.091 | 0.0021 |
| Transport gravel, macadam | 240 | 2.3 | 0.26 | 0.011 | 460 | 4.4 | 0.50 | 0.020 |
| Production sand | 16 | 0.13 | 0.015 | 0.00030 | 49 | 0.42 | 0.048 | 0.00093 |
| Transport sand | 190 | 1.8 | 0.21 | 0.0085 | 610 | 5.8 | 0.66 | 0.027 |
| Asphalting | 440 | 1.2 | 0.81 | 0.27 | 1200 | 3.4 | 2.2 | 0.74 |
| NETWORK | | | | | | | | |
| Transport pipe | 500 | 4.7 | 0.54 | 0.022 | 3900 | 37 | 4.2 | 0.17 |
| Welding of joints | 26 | 0.045 | 0.024 | 0.00055 | 46 | 0.080 | 0.042 | 0.00097 |
| Muffing | 250 | 1.3 | 0.83 | 0.020 | 380 | 2.1 | 1.3 | 0.033 |
| Testing of joints | 45 | 0.054 | 0.016 | | 18 | 0.022 | 0.0063 | |
| Electronic equipment | 4.9 | 0.013 | 0.14 | 0.000037 | 4.9 | 0.013 | 0.14 | 0.000037 |
| Waste handling | 5.2 | 0.050 | 0.0056 | 0.00023 | 5.2 | 0.050 | 0.0056 | 0.00023 |
| TRANSPORT WORKERS | 30 | 0.036 | 0.010 | | 42 | 0.050 | 0.015 | |
| **TOTAL** | **3800** | **44** | **5.4** | **0.44** | **10000** | **110** | **13** | **1.2** |

**Table 4:** Inventory results for the four studied dimensions for district heating network construction in a *green area* [2]. Unit: kg/100 m pipe system. Inventory results regarding emissions of fossil carbon dioxide, nitrogen oxides and sulphur oxides to air and emissions of compounds contributing to oxygen demand in water (measured as chemical oxygen demand, COD) are shown. The total results for the system as well as sub-results for the activities shown in Fig. 1 are given

| Network construction in *green area* | DN25, twin | | | | DN25, single | | | |
|---|---|---|---|---|---|---|---|---|
| **Inventory parameter** | **$CO_2$** | **$NO_x$** | **$SO_2$** | **COD** | **$CO_2$** | **$NO_x$** | **$SO_2$** | **COD** |
| TRENCH | | | | | | | | |
| Excavator | 430 | 8.1 | 0.39 | 0.020 | 520 | 9.7 | 0.46 | 0.024 |
| Earth, rock waste handling | 97 | 0.92 | 0.10 | 0.0043 | 130 | 1.2 | 0.14 | 0.0057 |
| Geotextile | 8.1 | 0.074 | 0.075 | 0.0027 | 12 | 0.11 | 0.11 | 0.0042 |
| Draining pipe | 79 | 0.49 | 0.48 | 0.012 | 79 | 0.49 | 0.48 | 0.012 |
| Marker band | 1.1 | 0.012 | 0.0070 | 0.00023 | 2.2 | 0.023 | 0.014 | 0.00046 |
| Production gravel | 5.1 | 0.036 | 0.0051 | 0.00012 | 7.9 | 0.056 | 0.0079 | 0.00018 |
| Transport gravel | 26 | 0.25 | 0.028 | 0.0011 | 40 | 0.38 | 0.043 | 0.0018 |
| Production sand | 6.9 | 0.059 | 0.0068 | 0.00013 | 8.7 | 0.075 | 0.0086 | 0.00016 |
| Transport sand | 85 | 0.80 | 0.092 | 0.0037 | 110 | 1.0 | 0.12 | 0.0047 |
| NETWORK | | | | | | | | |
| Transport pipe | 60 | 0.57 | 0.065 | 0.0027 | 120 | 1.2 | 0.14 | 0.0055 |
| Welding of joints | 4.0 | 0.0069 | 0.0037 | 0.000085 | 7.6 | 0.013 | 0.0070 | 0.00016 |
| Muffing | 33 | 0.20 | 0.12 | 0.0037 | 110 | 0.46 | 0.29 | 0.0068 |
| Testing of joints | 23 | 0.028 | 0.0082 | | 56 | 0.068 | 0.020 | |
| Electronic equipment | 2.4 | 0.0066 | 0.071 | 0.000018 | 4.9 | 0.013 | 0.14 | 0.000037 |
| Waste handling | 5.2 | 0.050 | 0.0056 | 0.00023 | 5.2 | 0.050 | 0.0056 | 0.00023 |
| TRANSPORT WORKERS | 8.8 | 0.011 | 0.0031 | | 10 | 0.013 | 0.0037 | |
| **TOTAL** | **880** | **12** | **1.5** | **0.052** | **1200** | **15** | **2.0** | **0.066** |
| | DN100, single | | | | DN500, single | | | |
| **Inventory parameter** | **$CO_2$** | **$NO_x$** | **$SO_2$** | **COD** | **$CO_2$** | **$NO_x$** | **$SO_2$** | **COD** |
| TRENCH | | | | | | | | |
| Excavator | 640 | 12 | 0.58 | 0.030 | 900 | 17 | 0.81 | 0.042 |
| Earth, rock waste handling | 230 | 2.2 | 0.25 | 0.010 | 820 | 7.8 | 0.88 | 0.036 |
| Geotextile | 18 | 0.16 | 0.17 | 0.0061 | 35 | 0.32 | 0.32 | 0.012 |
| Draining pipe | 79 | 0.49 | 0.48 | 0.012 | 79 | 0.49 | 0.48 | 0.012 |
| Marker band | 2.2 | 0.023 | 0.014 | 0.00046 | 2.2 | 0.023 | 0.014 | 0.00046 |
| Production gravel | 12 | 0.083 | 0.012 | 0.00026 | 22 | 0.16 | 0.022 | 0.00051 |
| Transport gravel | 59 | 0.56 | 0.064 | 0.0026 | 115 | 1.1 | 0.12 | 0.051 |
| Production sand | 16 | 0.13 | 0.015 | 0.00030 | 49 | 0.42 | 0.048 | 0.00090 |
| Transport sand | 190 | 1.8 | 0.21 | 0.0085 | 616 | 5.6 | 0.67 | 0.027 |
| NETWORK | | | | | | | | |
| Transport pipe | 500 | 4.7 | 0.54 | 0.022 | 3900 | 37 | 4.2 | 0.17 |
| Welding of joints | 26 | 0.045 | 0.024 | 0.00055 | 46 | 0.080 | 0.042 | 0.00097 |
| Muffing | 250 | 1.3 | 0.83 | 0.020 | 380 | 2.1 | 1.3 | 0.033 |
| Testing of joints | 45 | 0.054 | 0.016 | | 18 | 0.022 | 0.0063 | |
| Electronic equipment | 4.9 | 0.013 | 0.14 | 0.000037 | 4.9 | 0.013 | 0.14 | 0.000037 |
| Waste handling | 5.2 | 0.050 | 0.0056 | 0.00023 | 5.2 | 0.050 | 0.0056 | 0.00023 |
| TRANSPORT WORKERS | 13 | 0.016 | 0.0046 | | 18 | 0.022 | 0.0064 | |
| **TOTAL** | **2100** | **24** | **3.3** | **0.11** | **7000** | **72** | **9.0** | **0.34** |

**Fig. 4** shows the relative contribution to global warming from three phases in the life cycle of construction of district heating pipe networks. How the activities are grouped into phases is indicated in Tables 3 and 4:

- Trench: Excavation, handling of excavated materials, production and transport of material for refilling, including drainage and marking, refilling, and asphalting.
- Network: Production and transport of all pipe network constituents, and all pipe connection activities. Production of district heating pipes is not included.
- Transport workers: Transport of workers to and from the excavation site. For muffing and joint testing, transports of workers are included in subactivities and will therefore be a part of 'Network'.

The largest contribution to global warming is from the trench. Only for DN500 pipes alone in *green areas* is the environmental impact larger for the network than for the trench. The trench makes up a larger part in *urban environments* than in *green areas*, because in *urban environments*, asphalt removal and restoration has to be performed and no excavated material is reused during refilling. The pipe trench is also deeper in *urban environments* than in *green areas* to protect the pipes from the impact of traffic load. Less refilling material, thus, has to be handled in *green areas* and transports of excavated materials also decrease. Environmental impacts from transport of workers are negligible. Fig. 4 indicates that an important measure for reducing greenhouse gas emissions from construction of a district heating network is to minimise the excavation work. Thus, the pipe trenches should not be made larger than necessary. However, a decrease in excavation work must not be made to the extent that the working conditions of the entrepreneurs

**Table 5:** Characterisations and weightings for the four studied dimensions for district heating network construction in *urban environments*. All results are given per 100 m of pipe system

| | Excavator | Excavation waste (asphalt, earth, rock) | Geotextile, marker band, draining pipe | Macadam, gravel, sand | Asphalting | Transport pipe | Other network | Transport workers | Total |
|---|---|---|---|---|---|---|---|---|---|
| **CHARACTERISATIONS** | | | | | | | | | |
| **GWP [kg $CO_2$ equivalents]:** | | | | | | | | | |
| DN25, twin | 1100 | 210 | 90 | 250 | 240 | 62 | 70 | 22 | **2100** |
| DN25, single | 1400 | 280 | 95 | 330 | 300 | 130 | 190 | 28 | **2700** |
| DN100, single | 1500 | 440 | 100 | 520 | 460 | 520 | 340 | 31 | **3900** |
| DN500, single | 2300 | 1200 | 120 | 1200 | 1200 | 4000 | 470 | 43 | **11000** |
| **POCP [kg ethene equivalents]:** | | | | | | | | | |
| DN25, twin | 2.3 | 0.20 | 0.011 | 0.23 | 0.17 | 0.058 | 0.021 | 0.0072 | **3.0** |
| DN25, single | 2.8 | 0.26 | 0.012 | 0.31 | 0.20 | 0.12 | 0.053 | 0.0089 | **3.8** |
| DN100, single | 3.2 | 0.41 | 0.012 | 0.48 | 0.31 | 0.48 | 0.092 | 0.0099 | **5.0** |
| DN500, single | 4.8 | 1.1 | 0.014 | 1.2 | 0.84 | 3.8 | 0.12 | 0.014 | **12** |
| **AP [kg $SO_2$ equivalents]:** | | | | | | | | | |
| DN25, twin | 15 | 1.6 | 1.1 | 1.8 | 0.90 | 0.47 | 0.47 | 0.026 | **22** |
| DN25, single | 19 | 2.1 | 1.2 | 2.4 | 1.1 | 0.96 | 1.0 | 0.032 | **27** |
| DN100, single | 21 | 3.3 | 1.3 | 3.8 | 1.7 | 3.8 | 2.4 | 0.036 | **37** |
| DN500, single | 31 | 9.1 | 1.6 | 9.1 | 4.6 | 30 | 3.6 | 0.050 | **90** |
| **Resource depletion [$year^{-1}$]:** | | | | | | | | | |
| DN25, twin | 8.6 | 1.6 | 1.8 | 1.8 | 1.8 | 0.46 | 1.1 | 0.17 | **17** |
| DN25, single | 11 | 2.0 | 1.9 | 2.4 | 2.2 | 0.95 | 2.3 | 0.21 | **23** |
| DN100, single | 12 | 3.2 | 2.1 | 3.7 | 3.4 | 3.8 | 5.4 | 0.23 | **34** |
| DN500, single | 18 | 8.9 | 2.7 | 9.0 | 9.2 | 30 | 8.1 | 0.33 | **86** |
| **WEIGHTINGS** | | | | | | | | | |
| **EcoIndicator99 [Ecopoints]:** | | | | | | | | | |
| DN25, twin | 110 | 18 | 14 | 21 | 19 | 5.2 | 8.7 | 1.7 | **200** |
| DN25, single | 140 | 23 | 15 | 28 | 23 | 11 | 20 | 2.0 | **260** |
| DN100, single | 150 | 37 | 17 | 43 | 35 | 43 | 43 | 2.3 | **370** |
| DN500, single | 220 | 100 | 21 | 100 | 95 | 340 | 64 | 3.2 | **950** |
| **Ecoscarcity [thousands of Ecopoints]:** | | | | | | | | | |
| DN25, twin | 1200 | 160 | 69 | 180 | 140 | 47 | 33 | 4.3 | **1800** |
| DN25, single | 1500 | 210 | 73 | 240 | 170 | 97 | 77 | 5.4 | **2300** |
| DN100, single | 1600 | 330 | 76 | 370 | 260 | 390 | 160 | 5.9 | **3200** |
| DN500, single | 2500 | 910 | 88 | 900 | 690 | 3000 | 240 | 8.3 | **8300** |

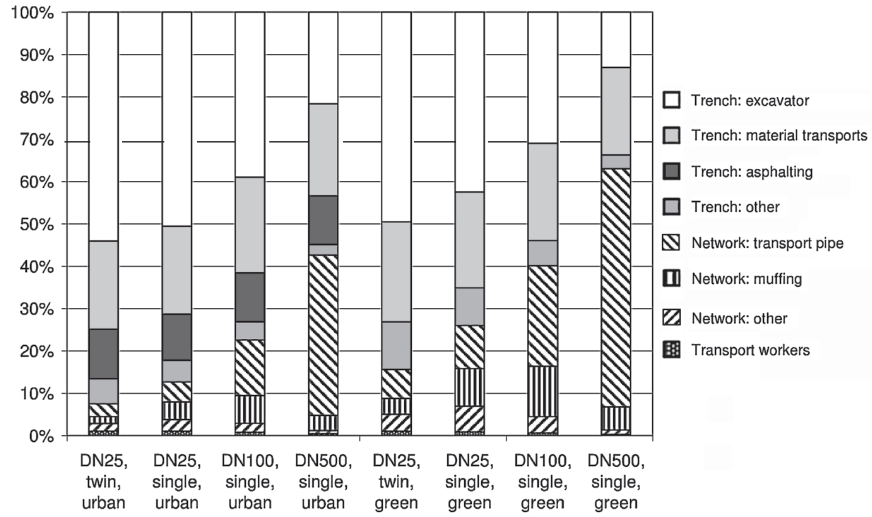


**Fig. 4:** The relative contribution to global warming from different parts in the life cycle of construction of district heating pipe networks. Four different dimensions in two different surroundings

**Table 6:** Characterisations and weightings for the four studied dimensions for district heating network construction in a *green area*. All results are given per 100 m of pipe system

| | Excavator | Excavation waste (earth, rock) | Geotextile, marker band, draining pipe | Gravel, sand | Transport pipe | Other network | Transport workers | Total |
|---|---|---|---|---|---|---|---|---|
| **CHARACTERISATIONS** | | | | | | | | |
| **GWP [kg $CO_2$ equivalents]:** | | | | | | | | |
| DN25, twin | 450 | 100 | 90 | 130 | 62 | 70 | 9.1 | **910** |
| DN25, single | 540 | 130 | 95 | 170 | 130 | 190 | 11 | **1300** |
| DN100, single | 670 | 240 | 100 | 290 | 520 | 340 | 14 | **2200** |
| DN500, single | 940 | 840 | 120 | 760 | 4000 | 470 | 19 | **7200** |
| **POCP [kg ethene equivalents]:** | | | | | | | | |
| DN25, twin | 0.93 | 0.094 | 0.011 | 0.12 | 0.058 | 0.021 | 0.0029 | **1.2** |
| DN25, single | 1.1 | 0.12 | 0.012 | 0.16 | 0.12 | 0.053 | 0.0035 | **1.6** |
| DN100, single | 1.4 | 0.22 | 0.012 | 0.27 | 0.48 | 0.092 | 0.0044 | **2.5** |
| DN500, single | 1.9 | 0.79 | 0.014 | 0.70 | 3.8 | 0.12 | 0.0061 | **7.3** |
| **AP [kg $SO_2$ equivalents]:** | | | | | | | | |
| DN25, twin | 6.1 | 0.75 | 1.1 | 0.93 | 0.47 | 0.47 | 0.011 | **9.8** |
| DN25, single | 7.2 | 0.99 | 1.2 | 1.25 | 0.96 | 1.0 | 0.013 | **13** |
| DN100, single | 9.1 | 1.8 | 1.28 | 2.1 | 3.8 | 2.4 | 0.016 | **20** |
| DN500, single | 13 | 6.3 | 1.6 | 5.5 | 30 | 3.6 | 0.022 | **60** |
| **Resource depletion [$year^{-1}$]:** | | | | | | | | |
| DN25, twin | 3.4 | 0.74 | 1.76 | 0.92 | 0.46 | 1.1 | 0.069 | **8.4** |
| DN25, single | 4.1 | 0.98 | 1.9 | 1.2 | 0.95 | 2.3 | 0.083 | **12** |
| DN100, single | 5.1 | 1.8 | 2.1 | 2.1 | 3.8 | 5.4 | 0.10 | **20** |
| DN500, single | 7.2 | 6.2 | 2.7 | 5.4 | 30 | 8.1 | 0.14 | **60** |
| **WEIGHTINGS** | | | | | | | | |
| **EcoIndicator99 [Ecopoints]:** | | | | | | | | |
| DN25, twin | 44 | 8.4 | 14 | 11 | 5.2 | 8.7 | 0.67 | **91** |
| DN25, single | 52 | 11 | 15 | 14 | 11 | 20 | 0.80 | **120** |
| DN100, single | 65 | 20 | 17 | 24 | 43 | 43 | 1.0 | **210** |
| DN500, single | 92 | 71 | 21 | 62 | 340 | 64 | 1.4 | **650** |
| **Ecoscarcity [thousands of Ecopoints]:** | | | | | | | | |
| DN25, twin | 480 | 75 | 69 | 92 | 47 | 33 | 1.8 | **800** |
| DN25, single | 580 | 99 | 73 | 120 | 97 | 77 | 2.1 | **1000** |
| DN100, single | 720 | 180 | 76 | 210 | 390 | 160 | 2.6 | **1700** |
| DN500, single | 1000 | 630 | 88 | 540 | 3000 | 240 | 3.6 | **5500** |

performing welding, muffing and foaming in the pipe trenches become too poor, since a high quality job is essential to avoid new excavations due to repair needs. Failures and leaks in Swedish district heating systems most commonly occur at joints; high quality work in jointing is thus important. The depth of the pipe in the ground has an effect on the heat losses. This will be discussed further in Part 3 of this article series.

How different activities contribute to total characterisation and weighting results is shown in **Table 7** (*urban environment*). The contributions are similar for all impact assessments shown in Table 7. Transport of workers is not shown because the contribution is very small; between 0.1 and 1.1% for all scenarios and all environmental impact assessment methods. Diesel production and use in the excavator gives the largest contribution in all cases except for a few environmental impact assessments of the largest pipe dimension. The transport between the pipe manufacturer and the pipe trench becomes important for large dimensions (heavy pipes). In this general case, a transport distance of 1000 km was assumed. Note that in specific cases, the transport distance may be much longer or much shorter.

In **Fig. 5**, network construction in *urban environments* and in *green areas* is compared. GWP for DN500 single pipes is shown. It is evident that the work performed in an *urban environment* gives rise to much larger emissions of greenhouse gases. Asphalting has a relatively large impact on the overall results; an activity not needed at all in *green areas*. In *urban environments*, all excavated material is removed from the site to minimise disturbances for traffic, etc. In *green areas*, some of the excavated material (about 20%) can be left on site and used as top filling while refilling the pipe trench. According to the guidelines for district heating pipe network construction [4], fine pit run material should surround the district heating pipes to avoid damages in the casing caused by pointy or sharp edges in crushed rock material. Research performed at Chalmers University of Technology and the Swedish Testing and Research Institute [20] indicates that more of the material can be left on site and reused without adverse effects on the pipes. If such methods are accepted in network construction, the environmental impacts from production and transport of macadam, gravel and sand, as well as the handling of excavated materials, can be reduced.

**Table 7:** The contribution to the total environmental impact from some activity groups in construction of district heating pipe networks in *urban environments*

| | | Transport pipe | Geotextile, marker band, draining pipe | Other network | Excavator | Excavation waste (asphalt, waste, rock) | Macadam, gravel, sand | Asphalting |
|---|---|---|---|---|---|---|---|---|
| **CHARACTERISATIONS** | | | | | | | | |
| **GWP** | DN25, twin | 3.0% | 4.3% | 3.4% | 54% | 10% | 12% | 12% |
| | DN25, single | 4.7% | 3.5% | 6.9% | 51% | 10% | 12% | 11% |
| | DN100, single | 13% | 2.6% | 8.7% | 39% | 11% | 13% | 12% |
| | DN500, single | 38% | 1.1% | 4.4% | 22% | 11% | 12% | 12% |
| **POCP** | DN25, twin | 1.9% | 0.37% | 0.70% | 77% | 6.6% | 7.8% | 5.5% |
| | DN25, single | 3.2% | 0.31% | 1.4% | 75% | 6.8% | 8.1% | 5.4% |
| | DN100, single | 9.7% | 0.25% | 1.8% | 63% | 8.2% | 9.6% | 6.3% |
| | DN500, single | 32% | 0.12% | 1.0% | 40% | 9.6% | 9.8% | 7.1% |
| **AP** | DN25, twin | 2.2% | 5.0% | 2.2% | 70% | 7.3% | 8.6% | 4.2% |
| | DN25, single | 3.5% | 4.3% | 3.6% | 68% | 7.6% | 8.9% | 4.0% |
| | DN100, single | 10% | 3.4% | 6.4% | 56% | 8.8% | 10% | 4.5% |
| | DN500, single | 34% | 1.8% | 4.1% | 35% | 10% | 10% | 5.1% |
| **Resource depletion** | DN25, twin | 2.7% | 10% | 6.2% | 50% | 9.0% | 11% | 11% |
| | DN25, single | 4.2% | 8.6% | 10% | 47% | 9.0% | 11% | 9.8% |
| | DN100, single | 11% | 6.4% | 16% | 35% | 9.6% | 11% | 10% |
| | DN500, single | 35% | 3.2% | 9.4% | 21% | 10% | 11% | 11% |
| **WEIGHTINGS** | | | | | | | | |
| **EcoIndicator99** | DN25, twin | 2.7% | 7.1% | 4.4% | 56% | 9.0% | 11% | 9.5% |
| | DN25, single | 4.2% | 5.9% | 7.8% | 53% | 9.1% | 11% | 9.0% |
| | DN100, single | 12% | 4.5% | 12% | 41% | 9.9% | 12% | 9.5% |
| | DN500, single | 36% | 2.2% | 6.8% | 24% | 11% | 11% | 10% |
| **Ecoscarcity** | DN25, twin | 2.6% | 3.8% | 1.8% | 66% | 8.7% | 10% | 7.4% |
| | DN25, single | 4.1% | 3.1% | 3.3% | 63% | 8.8% | 10% | 7.1% |
| | DN100, single | 12% | 2.4% | 4.9% | 51% | 10% | 12% | 7.9% |
| | DN500, single | 36% | 1.1% | 2.8% | 30% | 11% | 11% | 8.3% |

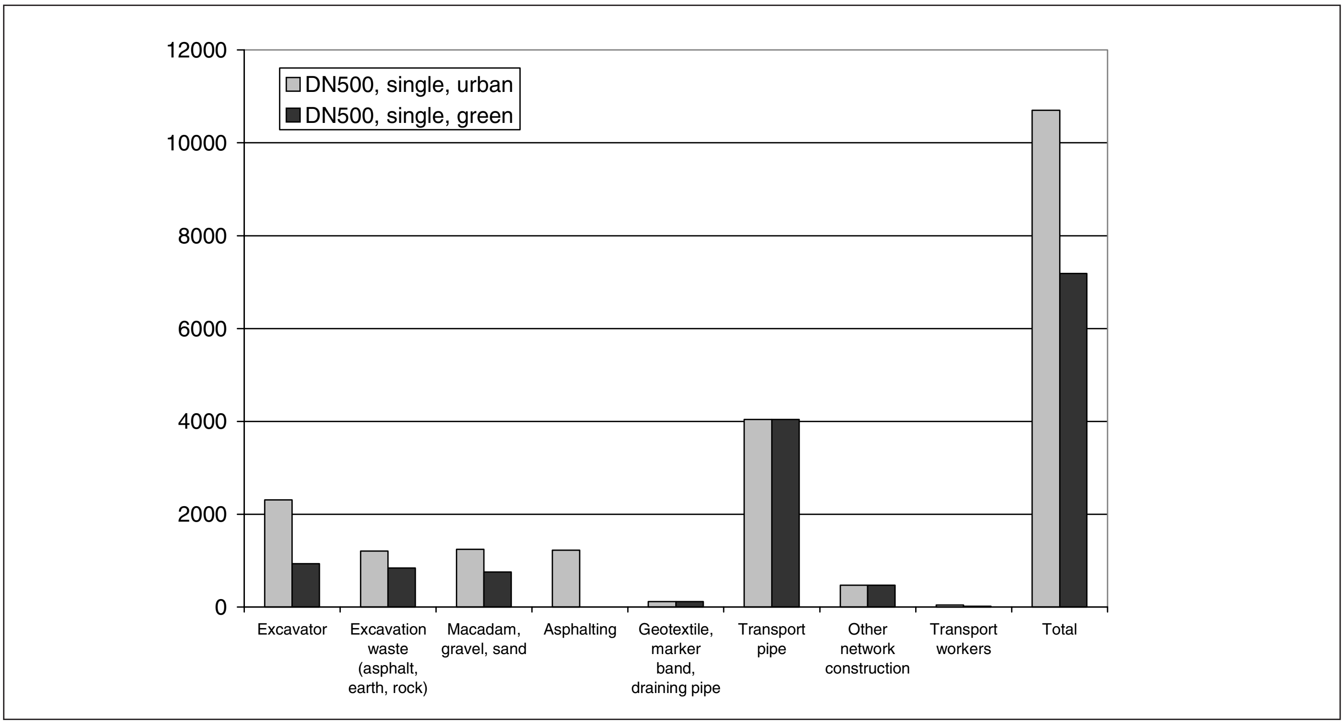


**Fig. 5:** Comparison between network construction in *urban environments* and *green areas*, respectively, for DN500 single pipes. GWP characterisation, unit: kg carbon dioxide equivalents per 100 m of pipe system

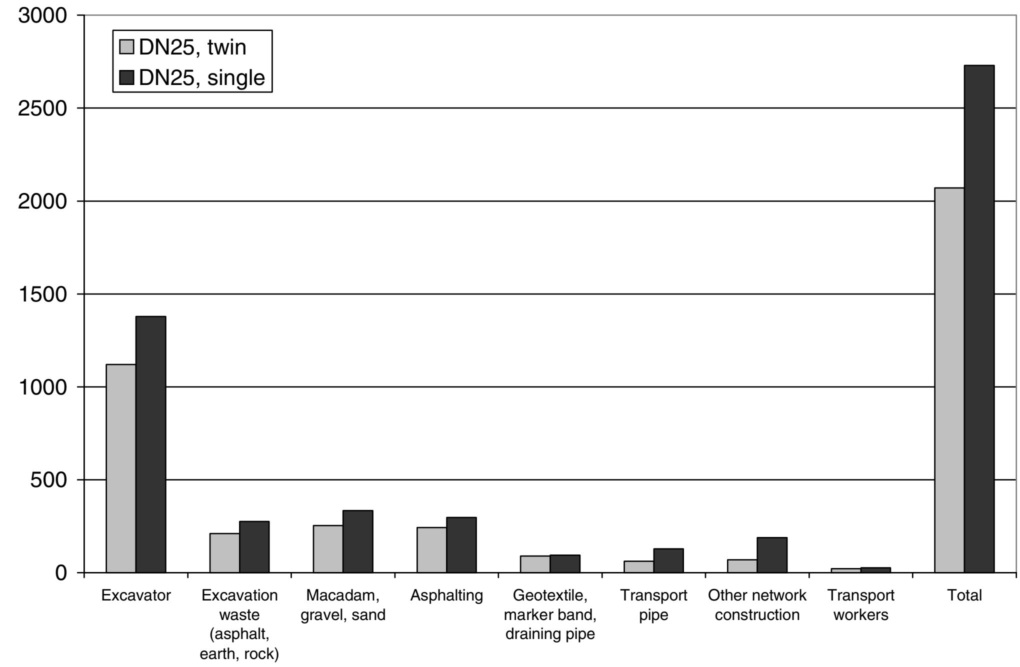


**Fig. 6:** Comparison of network construction with one twin pipe or two single pipes, respectively, of the dimension DN25 in an *urban environment*. GWP characterisation, unit: kg carbon dioxide equivalents per 100 m of pipe system

Different dimensions of district heating pipes are generally not comparable, since they do not have the exact same function. In this study, however, two of the cases may be compared. One twin pipe can be compared to two single pipes of the same steel tube dimension since they are able to transport the same amount of water. In **Fig. 6**, the GWP impact from network construction with one twin pipe or two single pipes of the dimension DN25, respectively, is compared. The two single pipes need a larger pipe trench volume than the twin pipe, resulting in a larger environmental impact from 'trench' activities. Also, less polyurethane and polyethylene is used in muffing, and the transported pipe weight is lower. As was shown in Part 1 of the article series [1], the environmental impact from production is also lower for one DN25 twin pipe than for two DN25 single pipes of equal length. For other pipe dimensions than DN25, the situation may be different. For small dimensions, the twin pipe construction has a lower heat transfer coefficient compared to corresponding single pipes of Series 2 insulation [21]. Heat losses from the pipes and the overall system performance will be discussed in Part 3 of this series of papers.

In Part 1 of this article series, results were published for production of district heating pipes [1]. In **Fig. 7**, results for the pipe production phase have been combined with the results for network construction from this study. Regarding

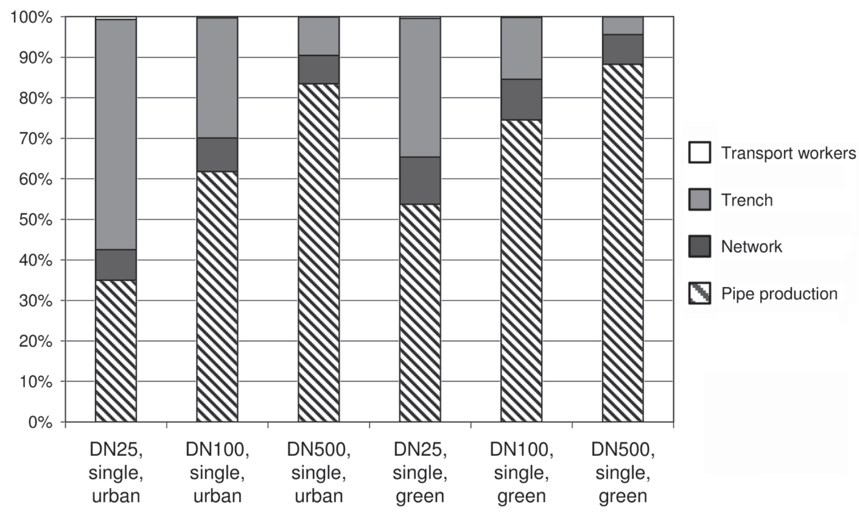


**Fig. 7:** Combined results for two phases in the life cycle of district heat distribution: 'Pipe Production' (see Part 1) and 'Network Construction' (split into trench, network and transport workers). GWP characterisation, unit: kg carbon dioxide equivalents per 100 m of pipe system

the three pipe dimensions shown, it is clear that pipe production causes the largest environmental impact for larger pipes, but that the importance of the two life cycle phases is almost equal for the smaller pipes. For the use phase, results will be published in Part 3 of the article series. Preliminary results, reported in Fröling (2002) [3], indicate that the environmental impact from use of the network is of great importance.

No cases of district heating network construction are identical. Things like ground conditions, pipe system layout, costs, demands from customers, etc will generate different solutions. The results presented here are valid only for the systems described. Results will, for example, change dramatically if the distance between the pipe manufacturer and the excavation site is much longer or much shorter than the assumed 1000 km. If the need for blasting is high, much larger efforts will have to be put into excavation than in the investigated cases.

Co-utilisation of pipe trenches for different types of pipes and cables is recommended because it decreases the need for excavation efforts in society. This will of course not change the volumes necessary to excavate in the construction of district heating networks, but the total environmental burden from excavation work in society would be less.

## 3 Conclusions

An important measure for reducing the environmental impact from the construction of a district heating pipe network is to minimise the excavation work. However, a decrease in excavation work must not be made to the extent that the working conditions of the entrepreneurs performing welding, muffing and foaming in the pipe trenches become too poor, since a high quality job is essential for avoiding new excavations due to repair needs.

Construction work performed in *urban environments* gives rise to larger environmental impacts than construction in a green area. Asphalting has a relatively large impact on the overall results, an activity which is not needed at all in *green areas*.

The transport between the pipe manufacturer and the pipe trench becomes important for large dimensions (heavy pipes).

The contribution of the transport of workers to the overall results is small; between 0.1 and 1.1% for all scenarios and all impact assessment methods.

One twin pipe can be compared to two single pipes of the same steel tube dimension and length, since they may transport the same amount of water. To use twin pipes whenever possible will decrease the pipe trench volumes and hence the excavation work and transport of excavated material.

When the two phases 'pipe production' and 'network construction' are compared, it is clear that pipe production causes the largest environmental impact for larger pipes, but that the importance of the two life cycle phases is almost equal for smaller pipes.

Co-utilisation of pipe trenches for different types of pipes and cables is recommended. This will not change the volumes necessary to excavate in the construction of district heating networks, but it decreases the need for excavation efforts in society.

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